Index

adaptive control, 3, 6, 11, 46, 114, 137, 150, 176, 323, 467, 494
robust self tuning, 5, 48
self tuning, 3, 5, 124, 175, 323, 494
adjoint, 64, 288, 429–431, 475, 596, 598, 600, 649
all-pass, 514
Astrom, K.J., 442
beam rolling mill, 295
benchmarking, 2, 40–45, 47, 55, 70, 72, 347, 354, 379–382, 634
introduction, 40–43, 70, 379
restricted structure, 41, 43, 44, 346, 379, 380, 382
nonlinear systems, 2, 42
Bernstein, D.S., 297
bilateral diophantine equation, 177, 182, 275, 403, 404
BISRA gaugemeter, 500, 507, 525, 546
Biss, D., 165
Blanke, M., 108
Bode, H.W., 51
Boekhoudt, P., 164, 296, 385
boiler feed pump control, 161
bounded real lemma, 14, 21, 23
certainty equivalent principle, 147
co-inner, 664
coke oven control, 36, 50
common factors, 98, 477
condition number, 337
continuous-time models, 57, 347, 416, 502
controller structures, 57, 58, 60, 117, 168, 336, 348, 351
feedback control, 351
feedforward control, 361, 374, 376, 629, 630
implementation, 40, 77, 299
reference or tracking controller, 70, 76, 361, 368, 374
single degree of freedom, 151, 168, 215
two degrees of freedom, 58, 159, 191, 255, 332, 346, 623, 626, 629
two and half degrees of freedom, 29, 57, 59, 91, 346, 371, 470, 495
coordinate measuring machine, 91, 110, 159, 162, 390, 410, 525
cost function, 31, 32, 38, 63, 64, 67, 69, 70, 79, 83, 94, 101, 119, 123, 124, 185, 199, 218, 256, 266, 276, 396, 401, 494, 504
cost weighting selection, 321, 648, 649
cross-product, 18, 171
dual criterion, 188
generalized, 29, 95, 158, 172, 321, 544
$G_{\infty}$ cost, 122
$H_{\infty}$, 8, 9, 10, 13, 19, 45, 113, 117, 121, 123, 147, 150, 250, 253, 258, 264, 267, 276, 390, 306, 310, 311, 321, 446, 452, 453, 649
mixed sensitivity, 11, 117, 124, 125, 153, 317
weighting definition, 158
cybernetics, 5, 6
dead-zone, 603, 605, 606, 613, 614, 617
design issues, 11, 113, 201, 543
classical design, 11
design rules, 76, 324
ideal response models, 62, 77, 191, 483

Robust Industrial Control Systems—Optimal Design Approach for Polynomial Systems
M. J. Grimble
© 2006 John Wiley & Sons, Ltd
design issues (Continued)
impractical design, 306
integral action, 74, 80, 144, 256, 470
interaction, 202
loop shaping, 324, 326
loop transfer recovery, 122, 335
measurement noise, 202
model reference, 92, 93, 106, 128, 203, 243, 473, 486, 568, 626, 640
output feedback, 202
performance, 11
simplified design, 249, 261, 262
safety critical, 530
stability margins, 11
tracking, 76
diesel engine, 160
discrete systems, 53, 109
supply, 178
worst case, 16, 114, 268, 270, 272, 276, 279, 280, 285, 288, 289, 553, 571
duality, 224, 440, 459, 462
dynamic matrix control, 192
electrical power, 177, 200, 201, 470, 471
expectation, 31, 150, 152–154, 271, 394, 628
fault detection, 5, 44, 54, 457, 554
linear systems, 595, 596, 634
nonlinear systems, 440, 595, 602, 603, 618, 623, 630
adaptive, 389, 390, 415, 426, 467, 494, 530
cost function, 395, 448, 449
deconvolution filtering, 390, 393, 410, 412, 421, 446, 453, 454
equalizing solution, 115, 116, 147, 264, 451, 456, 545
$H_2$ filtering, 391, 393, 395, 397, 419, 435, 437, 439, 441, 443
$H_\infty$ filtering, 445
inferential filtering, 440
Kalman filtering, 210, 232, 240, 291, 335, 410, 415, 428, 435, 439–442, 457, 528, 530
observers, 27, 28, 240
self-tuning filtering, 438
signal processing, 389, 390, 445, 458, 464
state estimation, 210
structure, 12, 13, 55, 168, 210, 232, 440, 448, 458
suboptimal, 445, 457
Wiener filter, 390, 395, 440
flight control, 235, 470, 485, 490, 494, 495, 497, 525, 530–532, 543, 593, 652
ASTOL aircraft, 485
classical design, 497
$H_2$ design, 48, 115, 303, 331, 333, 381, 535
Nichols diagram, 328, 489, 490, 542
root loci, 335
fuzzy control, 5, 6, 55
gain margin, 1, 135, 144, 336, 382
game problem, 16, 23, 268, 269, 275, 276, 283, 285, 288, 296, 459, 462
gas turbine control, 2, 132, 141, 163, 165, 241
control objectives, 242
models, 163
gauge control, see thickness control, 500, 501, 502, 510, 543, 546
generalized error, 272
$GH_\infty$ optimal control, 259
Glover-McFarlane design, 138, 262, 325
GLQG optimal control, 196–199

Greatest common divisor, 34, 61, 73, 93, 349

$H_2/H_\infty$ optimal control, 12

$H_\infty$ optimal control, 116, 118, 119
  auxiliary problem, 115, 118, 182, 184, 263, 448
  calculation, 12, 38, 75, 81, 116, 117, 128, 147, 253, 280, 287
  central solution, 285, 463
  cost function, 95, 96, 102, 114, 116, 147, 153, 218, 276, 306, 598
  equilizing solution, 115, 116, 147, 264, 451, 456, 545
  F-iteration solution, 148, 149
  $H_\infty$ norm, 272
  justification, 113, 121, 302, 529
  multivariable, 2, 14, 167, 178, 249, 250, 265, 268, 335, 337, 338
  one-block problems, 123, 124, 262
  standard system, 24, 57, 58, 89, 91, 95, 96, 102, 147, 461, 470, 503
  state-space approach, 45
  suboptimal, 250, 268, 273, 275, 284, 291, 457, 460, 463
  superoptimality, 258, 263, 264, 307
  two-block problems, 261
  weighting selection, 81, 146, 316, 332, 474, 521, 572, 647

Hardy space, 3

hang-on and hang-off, 487, 534

Horowitz, I., 51, 386

ideal response model, 62, 63, 117, 123, 194, 196, 346, 476, 483, 484

infimum, 654

inner, 149, 178, 179, 272, 510, 511, 588, 592, 600, 607, 647, 648

innovations, 21, 31, 167, 169, 170, 186, 199, 308, 427, 432, 458, 630

integral control, 614

inverse Nyquist array, 4, 335

Johnson, M.A., 111, 163, 246, 297, 442, 528, 651, 652


learning systems, 4, 57

long-range predictive control, 192

liquefied natural as plant, 106

LQ design, 4, 300


calculation, 35, 38

embedding, 115, 147, 249, 267

loop transfer recovery, 122, 335

measurement noise, 187, 196, 240

multivariable, 597

robust weighting, 82, 83, 84, 86, 146, 148, 186, 252, 253, 397, 402, 407, 413

standard system, 57, 58, 89, 91, 102

weighting selection, 81, 521, 572

M-circles, 328

MacFarlane A., 2

MATLAB 14, 53, 296, 386, 428, 467

diophantine equations, 31, 33, 85, 175, 176, 185, 193, 200, 275, 287, 402, 407, 462, 628, 630, 631

spectral factorization, 14, 274, 288, 290, 292, 464

marine controls, 340, 346


condition number, 337, 596
eigenvalues/vectors, 128, 249

Hermitian, 261, 289, 351

inverse, 381

matrix fraction description, 168

normal, 210, 232, 270, 399, 634

norms, 324

orthogonal, 214, 224, 229

numerical radius, 75, 265, 362

polynomial, 8, 15, 176, 183, 234, 250, 273, 399, 435, 451, 463

Schur complement, 30

singular value relationships, 324, 330, 331

singular values, 258

spectral radius, 331, 382, 656, 660

structured singular values, 330, 331

trace, 45, 64, 171, 174, 175, 186–189, 191, 217, 219, 222, 227, 234, 251, 272, 277, 280

transpose, 656, 664

unitary, 261

Mayne, D. W., 2

McMillan form, 336
minimum variance control, 41, 43, 48, 50, 55, 124, 623
model based predictive control, 2, 651
multivariable control, 48, 109–111, 190, 242, 244, 249–251, 338, 385, 561, 651, 652
interaction, 335, 380, 561
systems description, 168
multiple model control, 346
algorithm, 149, 362, 366, 368, 611
nonlinear control, 602, 607, 608, 633
Nehari problem, 259–261, 445
neural networks, 5, 6, 44, 624
Nevalina-Pick, 445, 466
Newton-Raphson iteration, 3
Nichols, N., 1
non-minimum phase, 120, 126, 203, 244, 263, 266, 385, 412, 413, 623, 651
non-linear control design, 595, 602
NL models, 440
NL systems, 440, 595, 602, 603, 618
NLQG, 595, 611, 649
NGMV, 596, 607, 623, 627, 628, 639, 647, 648, 649
Non-linear Smith predictor, 644, 645
normalized coprime factors, 262
norms, 8, 45, 268, 271
Chebyshev, 668
Euclidean, 272
Frobenius, 660, 666, 668
$H_{\infty}$, 1, 8, 45, 249, 268, 272
induced, 45
$p$ norms, 655
quadratic, 8
spectral, 251, 449
Nyquist diagram, 13, 316
observations signal, 19, 21, 61, 92, 191, 213, 225, 236, 238, 409, 429, 438, 458, 465
observers, 27
completing the squares, 286, 361, 649
cost function, 3, 150, 197, 198, 240, 259, 268, 300, 303, 360, 361, 650

cost terms, 98, 100, 101, 221, 227, 600
dual criterion, 110, 165, 245, 310, 385, 526
optimal control, 110, 165, 189, 245, 310, 385, 526
minimum cost, 186, 233, 286
optimization, 221
weighting terms, 240, 338, 351
output feedback, 1, 4, 24, 25, 28, 29, 230–234, 240, 292, 528, 607, 650
Pade approximation, 245
para-Hermitian, 664
Parseval’s theorem, 215, 634
performance specifications, 134, 301
Peterson, I. R., 463
phase margin, 1, 13, 52, 135, 299, 303, 316, 317, 336, 382, 543
poles and zeros, 1, 150, 306, 314, 336, 560, 561
cancellation properties, 308, 481
poles, 1, 306, 314, 336, 560, 561
zeros, 1, 150, 306, 314, 336, 560, 561
polynomial systems, 3, 13, 14, 267, 268, 308, 347, 485, 594, 596, 621
adjoint, 288, 430, 597
Bezout identity, 82, 83, 182, 183, 187, 200
common denominator, 168, 349, 625
common factors, 60, 93, 98, 119, 143, 148, 393, 477, 497, 584, 663, 664
diophantine equations, 31, 58, 389
generalized spectral factor, 97, 167, 626
J-spectral factor, 14, 273, 274, 288, 290, 292, 463, 464
mirror image polynomial, 315
Smith form, 661, 663
synthesis theory, 13
power systems, 246, 247
predictive optimal control, 2, 190, 244, 246, 387
generalized, 55, 111, 220
proportional, 13, 37, 178, 205, 319, 471, 521, 555, 556, 605
reference model, 93, 203, 571, 572, 580, 584,
614, 626, 639, 640, 650
relative gain array, 337
remotely operated vehicles, 580
$H_\infty$ design, 308, 535, 553, 554
modelling, 2, 7–9, 14, 136, 158, 210, 302,
602, 603
restricted structure control, 43, 60, 351, 353,
375, 376, 386, 387
RS controllers, 4, 41, 60, 351, 365
return difference, 228, 289, 321, 335, 438, 467
RMS gain, 272
Riccati equation, 14, 17, 18, 21, 23, 24, 46,
55, 57, 250, 268, 288, 290–293,
295, 415, 436, 438, 439, 445, 457,
463, 464, 466, 467, 601, 603, 623,
650, 652
robustness, 2, 10, 58, 82, 99, 103, 119, 121,
136, 208, 302, 320, 323, 326, 334, 352,
412, 451, 453, 456, 488
integrity, 2
poor robustness, 308, 320, 322, 323
uncertain systems modelling 136, 140, 151,
152, 155, 415
saddle point, 275, 281–283, 462
Schur, 30, 61, 67, 71, 73, 74, 76, 82, 86, 91,
93, 98, 100–103, 108, 119, 125–127,
129, 130, 148, 149, 155, 172, 174,
175, 183, 189, 192, 198, 213, 216,
219, 221, 223, 224, 228, 252, 254, 255,
263, 264, 266, 274, 279, 285, 306, 310,
311, 313, 315, 358, 393, 394, 396, 399,
401, 404, 406, 411, 451, 452, 455, 610,
631
Sebek, M., 110, 296, 467
Sendzimir mill, 297, 384
Shaked, U, 21, 23, 29, 167, 389, 390, 457
shape control, 297, 384, 553
ship control, 108, 111, 528, 593, 594
disturbances, 521
fin roll stabilization, 528
modelling, 81, 108, 589
positioning, 213, 585, 630
roll reduction ratio, 303, 523
roll stabilization, 528
rudder roll stabilization, 528
steering, 111
track keeping control, 588
wave model, 557, 563
spaces, 8, 52, 54, 271, 457
Hardy space, 3, 10
normed space, 665, 666
spray drying tower, 242
stability, 3, 8, 10, 12, 21, 29, 34, 121, 135,
136, 139, 183, 221, 299, 301, 316, 327,
331, 361, 453, 517, 603, 626, 633, 634,
636
characteristic equation, 173
criteria, 3, 46, 134
implied equation, 72, 87, 104, 119, 217,
220, 228, 255, 275, 353, 399, 400, 402,
611
robustness, 1, 3, 11, 76, 117, 121, 125,
134, 299–302, 316–318, 323, 325,
328, 330–332, 379, 381, 382, 475,
529–531
Stoorvogel, A., 52
submarine, 50, 337, 338, 340, 346, 382, 529,
554–556, 558, 560–563, 572, 576, 593
course control, 561
depth and pitch control, 561, 572
disturbances, 556, 562
modelling, 554, 555, 593
superheater temperature control, 177, 179,
245
sup regulator, 46, 54
supremum, 654
system description, 29, 115, 168, 212, 243, 269,
270, 454, 624, 631, 650
ARMAX model, 50, 147, 170, 208, 612
complementary sensitivity, 11, 104, 120, 170,
184, 319, 333, 381, 548, 549, 589
control sensitivity, 32, 64, 104, 120, 170, 184,
217, 218, 277, 312, 319, 321, 333, 334,
381, 548, 575, 589
equations, 57, 351, 650
LFT 24, 271
properties, 3, 11, 72, 117, 119, 304, 308, 314,
319, 331, 453, 481, 611
sensitivity functions, 62, 63, 72, 135, 152, 184,
187, 218, 225, 305, 317, 343, 477, 492,
509, 548, 576
sensitivity, 62–65, 72, 87, 120, 170, 184,
200, 257, 277, 308, 312, 333, 548,
589
standard system, 24, 50, 57, 58, 89, 91, 93–96,
102, 103, 284, 398, 402, 417, 448, 457,
458, 460, 502, 503, 561
stochastic, 29, 37, 50, 60, 198, 304, 308, 310, 648

control, 7, 323, 389, 426, 428, 440, 441, 443, 596–600, 602, 603, 611, 612, 616, 621, 623, 624, 627, 649–651
estimation, 389, 393, 415, 426–428, 431, 440, 441, 596, 613
thickness control, 89, 387, 415, 416, 425, 470, 500, 502, 510, 528, 530, 543, 546
beam rolling mill, 295
eccentricity, 415, 416, 425, 470, 501, 502, 530, 546
force measurement, 415, 502
gauge measurement, 501, 510
gaugemeter principle, 415, 500, 507, 546
$H_2$ design, 500
$H_\infty$ design, 546
Toeplitz form, 75, 129
tracking error, 30, 32, 43, 45, 63, 76, 94, 115, 117, 134, 242, 309, 324, 325, 358, 589, 590, 626
uncertainty, 2, 4, 5, 7–12, 15, 113, 114, 121, 136–147, 151–159, 249, 256, 296, 299, 300, 303, 313, 319, 322–324, 327–331, 591
additive, 136, 324, 331, 448
multiplicative, 163, 327, 331, 448, 553, 590
nominal model, 147
probabilistic, 114, 156–158, 196, 448
rational, 137
unstructured uncertainty, 9, 10, 114, 137
unilateral diophantine equation, 662
uniqueness, 176, 402
Wiener, N., 51, 247, 442
wind turbines, 386, 470, 484, 485, 526, 527
design, 470
disturbance spectra, 262, 263, 317
fixed and variable speed, 484
$H_\infty$ design, 334, 470, 484
$LQG$ optimal control, 8, 35, 36, 38, 57, 60, 106, 113, 171, 187, 196, 308
modelling, 527
power control, 133, 470
Youla parameterization, 49, 58, 82, 83, 126, 182, 183, 184, 187, 199, 200, 267
Zames G., 52
zeros see poles and zeros, 1, 306, 314, 336
$z$-transform, 8